Advanced Ceramic Coatings and Interfaces IV

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Preface

The Symposium on Advanced Ceramic Coatings for Structural, Environmental and Functional Applications was held at the 33rd Cocoa Beach International Conference on Advanced Ceramics and Composites in Cocoa Beach, Florida, during January 18-23, 2009. A total of 70 papers, including 8 invited talks, were presented at the symposium, covering broad ceramic coating and interface topic areas and emphasizing the latest advancement in coating processing, characterization and development.

The present volume contains twelve contributed papers from the symposium, with topics including vibration damping coatings, thermal and environmental barrier coating processing, testing and life modeling, non-destructive evaluation, multifunctional coatings and interfaces, highlighting the state-of-the-art ceramic coatings technologies for various critical engineering applications.

We are greatly indebted to the members of the symposium organizing committee, including Uwe Schulz, Yutaka Kagawa, Rodney Trice, Irene T. Spitsberg, Dileep Singh, Robert Vassen, Sophoclis Patsias, Yong-Ho Sohn, Anette M. Karlsson, and Ping Xiao, for their assistance in developing and organizing this vibrant and cutting-edge symposium. We also would like to express our sincere thanks to manuscript authors and reviewers, all the symposium participants and session chairs for their contributions to a successful meeting. Finally, we are also grateful to the staff of The American Ceramic Society for their efforts in ensuring an enjoyable conference and the high-quality publication of the proceeding volume.

DONGMING ZHU
H. T. LIN

Introduction

The theme of international participation continued at the 33rd International Conference on Advanced Ceramics and Composites (ICACC), with over 1000 attendees from 39 countries. China has become a more significant participant in the program with 15 contributed papers and the presentation of the 2009 Engineering Ceramic Division's Bridge Building Award lecture. The 2009 meeting was organized in conjunction with the Electronics Division and the Nuclear and Environmental Technology Division.

Energy related themes were a mainstay, with symposia on nuclear energy, solid oxide fuel cells, materials for thermal-to-electric energy conversion, and thermal barrier coatings participating along with the traditional themes of armor, mechanical properties, and porous ceramics. Newer themes included nano-structured materials, advanced manufacturing, and bioceramics. Once again the conference included topics ranging from ceramic nanomaterials to structural reliability of ceramic components, demonstrating the linkage between materials science developments at the atomic level and macro-level structural applications. Symposium on Nanostructured Materials and Nanocomposites was held in honor of Prof. Koichi Niihara and recognized the significant contributions made by him. The conference was organized into the following symposia and focused sessions:

Symposium 1	Mechanical Behavior and Performance of Ceramics and Composites
Symposium 2	Advanced Ceramic Coatings for Structural, Environmental, and Functional Applications
Symposium 3	6th International Symposium on Solid Oxide Fuel Cells (SOFC): Materials, Science, and Technology
Symposium 4	Armor Ceramics
Symposium 5	Next Generation Bioceramics
Symposium 6	Key Materials and Technologies for Efficient Direct Thermal-to-Electrical Conversion
Symposium 7	3rd International Symposium on Nanostructured Materials and Nanocomposites: In Honor of Professor Koichi Niihara
Symposium 8	3rd International symposium on Advanced Processing & Manufacturing Technologies (APMT) for Structural & Multifunctional Materials and Systems

Symposium 9	Porous Ceramics: Novel Developments and Applications
Symposium 10	International Symposium on Silicon Carbide and Carbon-Based Materials for Fusion and Advanced Nuclear Energy Applications
Symposium 11	Symposium on Advanced Dielectrics, Piezoelectric, Ferroelectric, and Multiferroic Materials
Focused Session 1	Geopolymers and other Inorganic Polymers
Focused Session 2	Materials for Solid State Lighting
Focused Session 3	Advanced Sensor Technology for High-Temperature Applications
Focused Session 4	Processing and Properties of Nuclear Fuels and Wastes

The conference proceedings compiles peer reviewed papers from the above symposia and focused sessions into 9 issues of the 2009 Ceramic Engineering & Science Proceedings (CESP); Volume 30, Issues 2-10, 2009 as outlined below:

- Mechanical Properties and Performance of Engineering Ceramics and Composites IV, CESP Volume 30, Issue 2 (includes papers from Symp. 1 and FS 1)
- Advanced Ceramic Coatings and Interfaces IV Volume 30, Issue 3 (includes papers from Symp. 2)
- Advances in Solid Oxide Fuel Cells V, CESP Volume 30, Issue 4 (includes papers from Symp. 3)
- Advances in Ceramic Armor V, CESP Volume 30, Issue 5 (includes papers from Symp. 4)
- Advances in Bioceramics and Porous Ceramics II, CESP Volume 30, Issue 6 (includes papers from Symp. 5 and Symp. 9)
- Nanostructured Materials and Nanotechnology III, CESP Volume 30, Issue 7 (includes papers from Symp. 7)
- Advanced Processing and Manufacturing Technologies for Structural and Multifunctional Materials III, CESP Volume 30, Issue 8 (includes papers from Symp. 8)
- Advances in Electronic Ceramics II, CESP Volume 30, Issue 9 (includes papers from Symp. 11, Symp. 6, FS 2 and FS 3)
- Ceramics in Nuclear Applications, CESP Volume 30, Issue 10 (includes papers from Symp. 10 and FS 4)

The organization of the Daytona Beach meeting and the publication of these proceedings were possible thanks to the professional staff of The American Ceramic Society (ACerS) and the tireless dedication of the many members of the ACerS Engineering Ceramics, Nuclear & Environmental Technology and Electronics Divisions. We would especially like to express our sincere thanks to the symposia organizers, session chairs, presenters and conference attendees, for their efforts and enthusiastic participation in the vibrant and cutting-edge conference.

DILEEP SINGH and JONATHAN SALEM
Volume Editors

Advanced Ceramic Coatings and Interfaces IV
Edited by Dongming Zhu and Hua-Tay Lin

OXIDES FOR HIGH TEMPERATURE VIBRATION DAMPING OF TURBINE COATINGS

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ABSTRACT

The mechanical damping behavior of several oxides in the kHz regime is compared. Over the temperature range from room temperature to 1000°C, three oxides with a high concentration of oxygen vacancies exhibit pronounced damping at intermediate temperatures. Based on the results and a simple analysis, it is concluded that a search criteria for identifying oxides with high damping is that they are defect crystal structures and have both high ionic conductivity and low thermal conductivity. An expression for the peak damping temperature is given.

INTRODUCTION

Oxide coatings are currently being applied to high-temperature turbine blades to provide a thermal barrier enabling the gas temperatures of turbines to be increased without raising the temperature of the surface of the metal blades. This has allowed dramatic increases in turbine efficiency and power in the last decade, a period over which the development of higher temperature creep resistant single crystal superalloys has reached a level of maturity [1, 2]. This success raises the possibility that oxide coatings may provide additional functionality other than thermal resistance alone. In this contribution we describe recent exploratory work to investigate the potential of oxides to provide vibrational damping. Measurements at kHz frequencies are emphasized since these correspond to flexural vibrations induced in blades as a result of buffeting as they successfully pass behind vanes and into the turbine gas flow.

As a starting point for explorations we have paid most attention to oxides that have very low thermal conductivity so that the primary selection criterion for selecting the oxide as a thermal barrier is not compromised. In addition to the current coating material, yttria stabilized zirconia (YSZ), several different oxides with low thermal conductivity have been identified in the last decade, as shown in figure 1. It is emphasized that the data shown is the intrinsic conductivity, measured for fully dense materials, and that the introduction of porosity and gaps during processing can dramatically reduce the conductivity as is practiced in current coating technologies.

EXPERIMENTAL DETAILS

The vibration system we have used to measure flexural damping up to ~ 1200°C has been fully described elsewhere [3, 4]. Briefly, a cantilever beam of the material, clamped at one end, is set into vibration by broad-band excitation and the vibrational spectrum of displacements of the free end is monitored by a non-contact laser vibrometer. The dimensions of the beam are chosen so that the first resonance mode is at kHz frequencies. The resonant frequency is measured and the spectral analysis software is used to determine the damping ratio from the width of the resonance. These measurements are repeated at different temperatures and both the elastic modulus and damping ratios are calculated as a function of temperature. Although the vibration measurements are very rapid, the physical size of the beams together with the necessity of having the entire clamping and vibration system inside the furnace to ensure constant temperature dictates that the overall system has a slow response time to changing temperatures, limiting the number of data points that can be recorded in a reasonable experimental period.

The oxides investigated were prepared from either oxide powders or powders prepared by standard solution routes. The powders were then compacted into discs and sintered to close to full density. The sintered disks were then cut to the shape of rectangular bars using diamond impregnated blades and subsequently diamond polished. Good surface finish is necessary to ensure high reflectivity of the laser beam used to monitor the beam displacements. For some samples, that were particularly transparent, a thin platinum metal film was deposited to increase the laser reflectivity. Careful grinding and polishing to ensure parallel sides of the beams is also necessary. Although fully dense oxides are not really required to make valid damping measurements, removal of flaws, particularly edge flaws, is desirable to ensure a firm grip in clamping the beam without breaking the sample while at the same time minimizing spurious vibrations and displacements. An experimental protocol was developed to ensure that the results were repeatable and reproducible.

RESULTS

An illustration of the damping of a typical TBC system, consisting of a 140 micron thick 7.6 mole % yttria-stabilized zirconia (7YSZ) coated PWA-1484 single crystal superalloy with an intermediary aluminide bond-coat, is shown in figure 2 together with the damping of an uncoated alloy. The comparison indicates that the 7YSZ coating produces damping at intermediate temperatures that is absent in either the bare superalloy or the aluminide coated superalloy. At the higher temperatures, above ~ 900°C there is a clearly defined damping peak superimposed on an increasing background. The higher temperature peak has been attributed to Ni and Al diffusional hopping in the □' phase of the superalloy but until our recent work the damping properties of this higher temperature regime had not been investigated [3]. The peak due to the YSZ occurs at a similar temperature as has previously been reported from low frequency internal friction measurements of single crystal zirconia [5] In these other works the damping has been attributed to oxygen vacancy diffusional hopping. Using polycrystalline YSZ beams, we have shown that there is also an increasing damping background with increasing temperature above about 950°C whose identity has not been determined. [4]

The damping behavior of the four oxides, alumina (Al_2O_3), 7YSZ, gadolinium zirconate ($Gd_2Zr_2O_7$) and yttrium zirconate delta-phase ($Y_4Zr_3O_{12}$), have been investigated to date. It has been found that alumina does not exhibit any significant damping in the kHz range up to at least 1100°C whereas the other oxides do as is shown in figure 3. Furthermore, their damping peaks occur at significantly different temperatures, albeit at moderate temperatures in the range of 200-500°C.

DISCUSSION

In contrast to metals, comparatively little is known about the damping mechanisms in oxides, the magnitude of the damping attainable at different frequencies or their temperature dependence. In metals, damping can originate from a variety of defect mechanisms. For instance, the motion of interfaces, such as glissile twin interfaces in thermoelastic martensites or magnetostrictive alloys, from diffusional processes, such as Ni and Al vacancy diffusion in gamma-prime Ni_3Al, and from dislocation climb. These typically occur at relatively low frequencies. At very high frequencies, at MHz to GHz frequencies, energy can be dissipated by anharmonic phonon interactions, the so-called Akhiezer damping. At intermediate frequencies, thermoelastic damping can operate in all classes of material to a lesser or greater extent. This form of damping is associated with the generation of heat through the thermoelastic effect and the time constant for its flow from the hotter parts to the cooler parts of a solid during a vibrational cycle. The extent of damping depends on only on the material and its thermal diffusivity but also on the stress state. In the simplest case, that of a purely compressional vibration wave, heat is generated in the regions in compression and cooling occurs in the expanded part of the wave, so heat flows from the compressional to tensile regions of the material.

In the ceramics literature, damping in simple oxides such as rutile (TiO_2) and of thoria (ThO_2) containing CaO [6] and ZrO_2 has been identified with point defect reorientation under vibrational stresses. These classic studies, performed by standard internal friction measurements, have indicated that damping can occur by either cation interstitials (in rutile) or oxygen vacancies (in thoria), and give rise to damping peaks at relatively low temperatures, less than about 250°C. Since those early studies, almost all the measurements have since been on stabilized zirconia. These studies, which have been at low frequencies [7], have generally been performed to elucidate mechanisms of defect diffusion and its relation to ionic conductivity rather than of damping *per-se*.

The results shown in figure 3 clearly indicate that all three of the oxides measured to date other than alumina exhibit significant damping at intermediate temperatures. Furthermore, although damping is believed to originate from similar defect mechanisms there is a clear difference in the peak temperature. A common feature of the three oxides not shared by alumina is that they are all defective oxides, containing a high concentration of oxygen vacancies. In the case of the YSZ, the vacancies are associated with the concentration of Y^{3+} ions used to stabilize the YSZ. In both the $Gd_2Zr_2O_7$ and $Y_4Zr_3O_{12}$ compounds, the vacancies are intrinsic to their crystal structure. All three of the oxides have both exceptionally low and almost temperature-independent thermal conductivity [8], which is attributed to extensive phonon scattering as well as a mean free path being governed by the spacing of the vacancies. Based on these considerations, it is considered that the vibrational damping we observe is also associated with the vacancies in these compounds. If this is indeed correct, then this provides some guidance as to other possible oxide compounds that will also exhibit damping. There is some basis for this conclusion as discussed in the following paragraph.

At the present time, it is not possible to predict *a-priori* the peak damping temperatures for point defect damping of different compounds. However, some guidance comes from the analysis of defect relaxation originally presented by Wachtman [6]. He considered the rearrangement of point defects that could adopt a variety of equivalent crystallographic sites and how an alternating field affects the number on each site as they respond to the field. In effect, the point defect configurations represent different defect dipoles and in response to the applied field direction, the point dipoles reorient by the point defects diffusing to equivalent configurations but with lower energy. The energy dissipation is then controlled by the vibrational frequency applied and the diffusional jump rate. The latter, which depends on the energy barrier between the different defect sites, is related to temperature by an activation energy, E_i, similar to that for diffusion. The relationship that Wachtman derives between the damping factor, Q^{-1}, temperature, T, frequency, ω , and relaxation time, τ , can be expressed as

$$Q^{-1} = \frac{A\,Y\,N}{k_B T}\,\mathrm{sech}\left[\ln(\omega\,\tau) + {E_i}/{k_B T}\right] + \frac{constant}{T} \qquad (1)$$

where Y is Young's modulus, N is the concentration of defects, k_B , is Boltzmann's constant and A is a constant that depends on the material. The damping factor then depends on temperature in a number of distinct ways, explicitly in the reciprocal in the first term and through the activation energy in the relaxation rate. As can be judged visually from the fit to our data in figure 3, the form of equation 1 captures the functional dependence on temperature exhibited by the three oxides. The equation also provides another insight, namely the dependence of the damping peak temperature, T_P. From examination of the form of equation 1, the damping peak occurs when the term inside the *sech* has a zero value, namely

$$T_P = \frac{E_i}{k_B\,|\ln\omega\,\tau|} \qquad (2)$$

Although Wachtman's analysis is based on a dilute concentration of defects whereas the concentration of defects in the oxides we have studied is of the order of tens of percent, it has a number of dependencies that can be correlated with other properties. For instance, the dependence of damping on a high concentration of defects is consistent with the requirement for producing low thermal conductivity by phonon-defect scattering. Similarly, the dependence on low activation energy for diffusional hopping from one site to another is consistent with an oxide having high ionic mobility and hence conductivity. More rigorous evaluation on a larger number of oxides is needed before Wachtman's analysis can be demonstrated to be a robust guide to other oxides but it does support the conclusion that high damping factors can be expected from defective oxides.

Finally, although the foregoing discussion has been concerned with damping associated with point defects, it does not rule out the possibility that other damping mechanisms, such as ferroelastic twinning, might operate in other oxides. Nevertheless, it does suggest that high ionic conductivity and low thermal conductivity will be useful criteria in identifying candidate oxides for damping applications.

CONCLUDING REMARKS

The results presented in this work suggest that defective oxides may hold promise as coating materials combining the functionalities of serving as a thermal barrier coatings and damping elements in future turbine blade designs. The coatings investigated to date exhibit damping at temperatures more appropriate to certain compressor turbines stages and hence have the potential of being implemented to complement existing, mechanical damping schemes. Furthermore, the observation that the damping peak temperature varies from oxide to oxide, suggests that there is scope in using existing crystal chemistry rules together with othe property correlations for identifying oxides that could exhibit damping at still higher temperatures.

ACKNOWLEDGEMENTS

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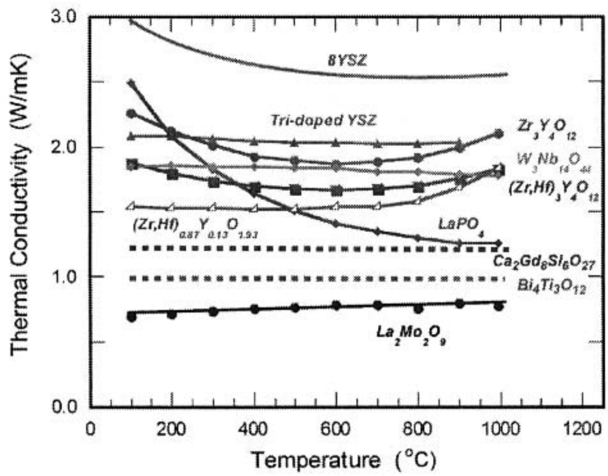

Fig 1. Thermal conductivity of a variety of oxides as a function of temperature. The data, obtained by thermal flash measurements, is for fully dense oxides.

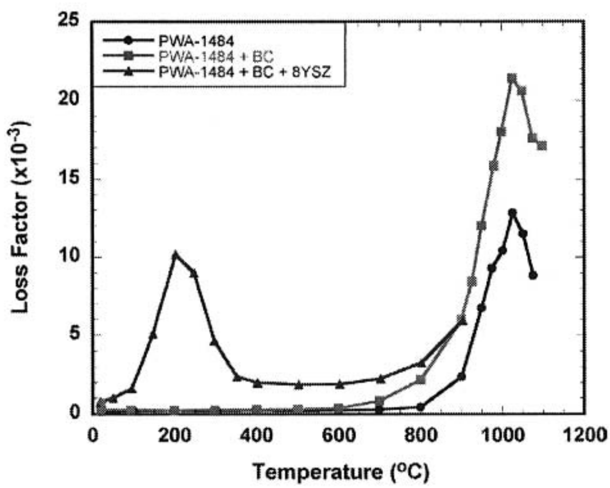

Fig 2. First resonance flexural vibration mode damping as a function of temperature for a thermal barrier coating system as well as data for the PWA 1484 superalloy together with an aluminide bond coated (BC) superalloy .

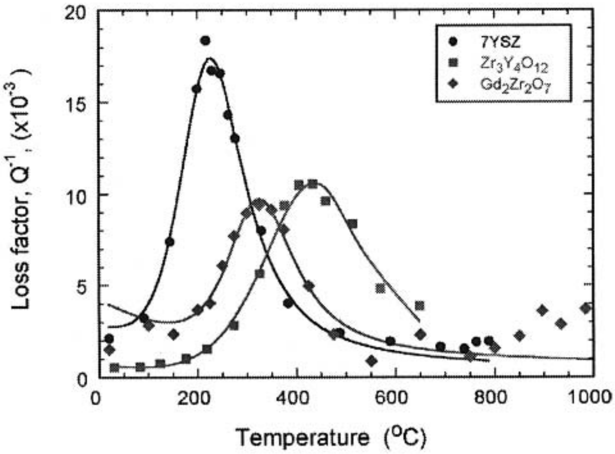

Fig 3. Comparison of the temperature dependent flexural damping of three defective oxides in the kHz frequency range. The curves through the data are the best fit to the functional form of equation 1 in the text.

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ENHANCING THE PASSIVE DAMPING OF PLASMA SPRAYED CERAMIC COATINGS

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ABSTRACT

Hard coatings deposited by plasma spray can dissipate vibratory energy as well as enhance the ability of turbine components to withstand the environment. However, with no other dissipative mechanism, reducing system quality factors (Q) in bending vibration to a target of 100 while increasing thickness no more than 10% requires a material loss modulus of at least 3.7 GPa (0.54 Mpsi) at strains of interest. Such ceramics as magnesium-aluminate spinel, alumina, titania-alumina, and yttria stabilized zirconia have been found to have loss moduli of only 1 -2 GPa. Preliminary work has shown that vacuum infiltrating alumina with a viscoelastic material (VEM) chosen for effectiveness at about 200F (93C) increased the loss modulus at strains of 400 ppm by a factors of 2 at room temperature and 3 at the design temperature. Infiltration of plasma-sprayed titania-alumina with the same VEM showed increases of factors of 3 and 4, respectively. An infiltrate with a higher glass transition temperature enables high damping at higher temperatures. In current work, particles of high temperature viscoelastic material (HTVEM) are co-sprayed with yttria stabilized zirconia. Preliminary results at low levels of strain suggest that the loss modulus of such materials at 1000-1400F (540-760C) may be as much as four times that obtained with the low temperature infiltrate at 93C.

INTRODUCTION

The requirement for increasing damping of components in modern turbine engines, particularly those used in aircraft, has been a subject of special emphasis in the National Turbine High Cycle Fatigue (HCF) Program that was initiated in 1994. Some of the drivers for the increased interest in damping include the increased utilization of Integrally Bladed Rotors (IBRs), or BLISKS, and high stage loadings with lower aspect ratio blades and vanes. IBR structures, in which the blades and rotor are a single piece, have less inherent damping than rotors with inserted blades that dissipated some energy, due to friction, in the dove-tail interfaces. Lower aspect ratio airfoils have resulted in higher modal densities of high order, high frequency modes, making the task of avoiding the excitation of these modes much more difficult. At some operating conditions a frequency of excitation from aerodynamic wakes can coincide with a resonant frequency of a blade. Once a resonant mode is excited and sustained the only thing limiting the maximum stress in the blade is damping.

Several approaches to increasing the damping of turbine engine components have been investigated. Some of these approaches include better modelling of frictional damping to improve designs of blade shrouds, platforms, and wedge dampers between blades; internal stick dampers inside blades, air film dampers, hollow blades filled with viscoelastic materials, embedded viscoelastic constrained layers, and coatings. None of these approaches are a universal panacea that will solve all resonant response problems that present a risk of HCF failures. Damping coatings, however, show promise of being one of the least invasive methods for increasing damping of specific components in a turbine engine. It is important to remember that turbine engine damping coatings must do much more than damp resonant vibrations. To be effective these coatings must be able to survive the severe creep, erosion, impact and fatigue environments associated with turbine engines.

BACKGROUND

The properties of the damping coatings investigated in this program have been modeled in terms of complex Young's modulus, E^*. Where

$$E^* = E_1 + jE_2 = E_1(1+j\eta)$$

and, by definition,

E_1 = Young's Storage Modulus

E_2 = Young's Loss Modulus

η = Loss Factor $= E_2/E_1$ (1)

The coatings are considered to be free-layer damping treatments, analyzed by Öberst [1]in 1952, consisting of a homogenous layer with complex modulus attached to an elastic beam. A free-layer coating on a single side of a beam is illustrated in Figure 1.[2]

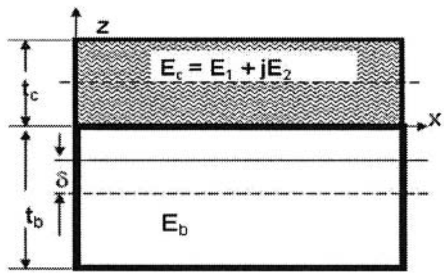

Figure 1. A Free-Layer Damping Coating on a Beam[2]

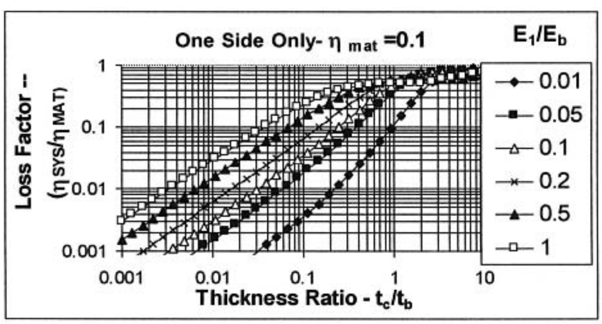

Figure 2. Normalized System Loss Factors (1/Q) of a Beam with a Free-Layer Damping Coating[2]

Plasma spayed ceramic coatings are not strictly homogeneous layers, as they typically consist of a thin bond coat with a thicker top coat, but characterization of the combined bond coat/top coat system as a single free-layer damping coating gives valid engineering data. If the usual simplifying assumptions are made that the coating is thin compared to the beam and that shear deformations can be neglected, damping performance is proportional to the thickness ratio (t_c/t_b) and the loss modulus of the free layer coating, as illustrated in Figure 2[2]. For a given thickness of a damping coating, the one measure of damping merit is loss modulus.

POLYMERIC FREE-LAYER DAMPING COATINGS

The original free-layer damping treatments, analyzed by Öberst, were polymeric viscoelastic damping layers. In the early 1960's Monsanto and Lord Manufacturing Company collaborated in marketing a free-layer damping treatment called LD-400. This material was developed and sold primarily for the reduction of noise radiating from heavy steel structures undergoing resonant response in thermal environments close to room temperature. LD-400 was an exceptional free layer damping treatment due to its high loss modulus which was achieved by filling the co-polymer matrix with flake graphite and orienting the flakes parallel to the surface of the material[3]. As with all viscoelastic materials, the damping properties of LD-400, expressed in terms of complex modulus, are functions of both temperature and frequency. Figure 3 shows damping properties of LD-400 at 1000 Hz, as developed from measurements.

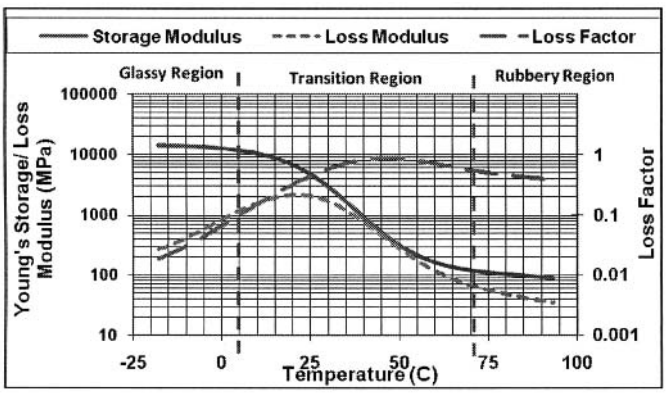

Figure 3. Damping Properties of LD-400 at 1000 Hz.

The properties shown in Figure 3 exemplify the behavior of viscoelastic polymers. At cold temperatures (<10C for LD-400) the storage modulus is high and the loss factor and loss modulus are low. This temperature region is referred to as the "glassy" region. As temperature increases the storage modulus drops rapidly as a function of temperature in the "transition" temperature region (>10C <70C for LD-400) and the loss factor peaks. The loss modulus peaks in the lower part of the "transition" temperature region. At higher temperatures the storage modulus levels off accompanied by a reduced loss factor and loss modulus in the "rubbery" region (>70 C for LD-400). It can be seen from Figure 3 that LD-400 exhibits excellent damping properties at 1000 Hz near room temperature, and has a loss modulus > 1000 MPa in the temperature range >5C and < 40C. LD-400 remains an example of one of the most effective polymeric free-layer damping treatments.

Although free-layer polymeric damping treatments have been successfully applied in industrial noise control of heavy steel structures, they are not appropriate for most aerospace applications. Free-layer polymeric damping treatments are too heavy, too thick and too sensitive to creep and erosion deterioration to be seriously considered for use in most aircraft turbine engines.

PLASMA SPRAYED CERAMIC DAMPING COATINGS

One class of free-layer damping treatments that has been considered for use in turbine engines is plasma sprayed ceramic coatings. Such ceramics as magnesium-aluminate spinel, alumina, titania-alumina, and yttria stabilized zirconia have been found to have significant damping.[4] Unlike viscoelastic materials (VEM), these hard ceramic coatings are not very sensitive to changes in temperature or frequency, but they are non-linear with respect to dynamic strain, i.e., the material properties are dependent on amplitude of strain. At very low vibratory strains these plasma sprayed coatings exhibit insignificant values of loss modulus. As dynamic strain increases these coatings show a reduction in storage modulus and an increase loss modulus. At dynamic strains of approximately 400 micro-strain typical values of loss modulus are in the 1-2 GPa range.[4, 5, 6] Damping mechanisms in these plasma sprayed coatings have been identified as friction at micro-cracks that are both parallel to and perpendicular to the surface of the coating.[5] Although damping in these plasma sprayed ceramic coatings can be significant, the loss modulus is not sufficient to reach the design goal of a resonant amplification factor Q of less than 100 in typical airfoils with a total coating thickness < 10% of the airfoil thickness.

At the 8th National Turbine High Cycle Fatigue (HCF) Conference, 2003, investigators at Rolls Royce indicated that they had achieved >50% increase in damping by vacuum infiltrating polyurethane into a plasma sprayed ceramic coating.[5] In subsequent investigations by APS Materials Inc., teamed with Universal Technology Corporation (UTC), it was demonstrated that the damping (loss modulus) of a plasma sprayed ceramic coating could be increased by a factor of about two at room temperature[6] and a factor of at least 3 at the design temperature[7] by infiltrating a carefully optimized polymeric viscoelastic material (VEM). Figure 4 shows the effect of infiltrating a VEM on the loss modulus of a plasma sprayed alumina coating with a NiCrAlY bond coat at room temperature and at high temperatures. Figure 5 illustrates the influence of the infiltrate on the storage modulus of the alumina coating. It is important to note that the plasma sprayed ceramic coatings investigated by APS Materials Inc. were not porous coatings. These coatings had densities >95% and the amount of infiltrated VEM was very small. As the damping of the infiltrated coatings is temperature sensitive, specific VEMs were selected to match the thermal environments of the components operating in the cold section of the engine. Plasma sprayed ceramic coatings, blends of alumina and titania, were infiltrated with a VEM optimized for application on specific turbine engine fan blades. They were tested in a spin-pit to centrifugal loads of 80,000 G at temperatures up to 200C with no indication of creep. Tests on these coatings showed no significant reduction in erosion resistance when compared to that of the bare blade.